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The Effectiveness of Assemblr Edu-Based Augmented Reality and Audio Media in Enhancing Science Concepts Understanding: A Quasi Experimental Design

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ABSTRACT
Conventional science instruction often relies on audio-based media, which often fails to help elementary students visualize complex, abstract scientific concepts, leading to suboptimal conceptual understanding. This study aimed to examine the effectiveness of Augmented Reality (AR) media in enhancing elementary students' conceptual understanding of science compared to audio-based media. A quasi-experimental design with a non-equivalent control group was employed, involving 50 fifth-grade students who were evenly assigned to experimental and control classes. Data were collected through pretests and posttests and analyzed using N-gain scores, effect size calculations, normality and homogeneity tests, and t-tests. The results showed that the experimental class achieved a mean pretest score of 41.6 and a posttest score of 67.2, while the control class achieved mean pretest and posttest scores of 42.6 and 49, respectively. The N-gain analysis showed greater improvement in the experimental class (0.44, moderate category) than in the control class. The effect size of 1.49 demonstrated a strong influence of AR-based media on students' learning outcomes. Furthermore, the t-test results confirmed significant differences both within groups (pretest–posttest) and between groups (posttest), emphasizing the superiority of AR media in science learning. It can therefore be concluded that Assemblr Edu-based AR media significantly improve elementary students' conceptual understanding of science.

Keywords: *augmented reality, students' science concepts, science learning, audio media learning*

INTRODUCTION

The teaching of Science (*Ilmu Pengetahuan Alam*, IPA) at the Elementary School (*Sekolah Dasar*, SD) level constitutes a crucial foundation for developing scientific literacy and critical thinking skills from an early age (Broström, 2016; Dykstra, 2017; Fani & Armağan, 2022). The primary objective of Science education in elementary schools is to enable students to grasp fundamental scientific concepts and cultivate logical and systematic scientific thinking abilities (Gormley et al., 2019; Lee, 2018). However, the instructional process for Science at this level frequently encounters several challenges, particularly in students' comprehension of abstract concepts such as force, energy, the water cycle, and light. This situation is exacerbated by the persistent dominance of conventional teaching methods and the minimal use of innovative instructional media that align with the cognitive development characteristics of elementary school children. In the era of Society 5.0, these challenges become more pressing as students are required to move beyond basic memorization toward a deeper, multi-dimensional understanding of natural phenomena (Ali et al., 2023; Gregory, 2019; Ranti et al., 2024).

One instructional medium still commonly used is two-dimensional visual aids and audio content, such as teacher-recorded voices, narrative explanations, or educational podcasts. While these media are effective in delivering verbal information and enhancing listening focus, they possess significant limitations in providing a realistic visualization of scientific concepts (Arici et al., 2019; Fitriani et al., 2023; Kouser & Majid, 2021). A preliminary study conducted at SDN 16 Koto Baru, through classroom observations and interviews with teachers, revealed that students frequently struggled to visualize abstract processes, resulting in average science scores consistently below the minimum mastery criterion (KKTP). Teachers noted that, despite using audio-based explanations, students often held misconceptions about the spatial relationships among scientific objects. Conventional media, such as printed textbooks and audio instructions, often fail to provide the spatial dimensions needed to understand complex scientific structures (Madanipour & Cohrssen, 2019; Nirmala & Sukardjo, 2024; Yanti et al., 2025). Another shortcoming is the students' inability to directly observe processes or phenomena, which may lead to sub-optimal comprehension of abstract concepts (Rahayu et al., 2020). These observations underscore the urgent need to explore alternative media that can provide more concrete visual representations.

In response to these limitations, *Augmented Reality* (AR) technology has emerged as a viable technology-based instructional alternative, offering three-dimensional visualization, interactivity, and a more immersive learning experience (Akçayır & Akçayır, 2017; Bacca et al., 2014). AR enables students to view scientific objects realistically via mobile devices, thus facilitating a more concrete and comprehensive conceptual understanding. In the context of science education, AR technology has proven effective in helping students understand complex concepts that are difficult to visualize through conventional media (Siki & Leba, 2025; Yoon et al., 2017). A study by Xu *et al.* (2022) further indicated that using AR in Science instruction has a significant positive effect on student learning outcomes, with an effect size (*Cohen's d*) of 0.74, categorized as moderate to large. The emergence of AR has offered a transformative solution to these educational barriers because, unlike Virtual Reality (VR), it allows students to maintain a connection with their physical classroom and peers while interacting with digital overlays (Camba et al., 2016; da Silva et al., 2019; Pellas & Vosinakis, 2018). This hybrid environment is particularly effective for primary education as it aligns with the cognitive development stage of children who require concrete operational experiences to grasp abstract ideas (Garzón et al., 2019).

One AR platform widely utilized in the educational sphere is *Assemblr Edu*. This application enables both educators and students to create and access interactive 3D objects that can be displayed directly onto real-world space via a mobile device camera (Chang et al., 2022; Haleem et al., 2022; Teo et al., 2021). *Assemblr Edu* supports constructivist-based learning by allowing students to perform independent exploration and observation of scientific objects (Ibáñez & Delgado-Kloos, 2018). Research by Yusuf & Wulandari (2025) indicates that AR media based on *Assemblr Edu* possesses high feasibility for instruction, evidenced by an expert media feasibility score of 90% and a student learning outcome improvement (*N-Gain*) of 0.72 (high category) in middle school mathematics. In the context of science education in elementary schools, a study by Maulidiyah *et al.* (2023) demonstrated that using *Assemblr Edu* for the water cycle topic successfully increased student achievement from 83.46% to 92.69% across two instructional cycles

Although this study employed the Classroom Action Research method, its findings strongly suggest that AR media like *Assemblr Edu* can positively impact students' scientific conceptual understanding. Assemblr Edu has emerged as a user-friendly AR platform that enables teachers to implement high-quality 3D content without advanced programming skills, thereby democratizing access to high-end educational technology in regional schools (Andrianu et al., 2025; Maharani & Aji, 2023; Sánchez-Cruzado et al., 2021). Furthermore, its multi-sensory nature caters to diverse learning styles, including visual, auditory, and kinesthetic, fostering a more inclusive science classroom (Cai et al., 2021; Gumilar et al., 2025; Nurqualbiah et al., 2025; Thees et al., 2020).

These four studies share a common approach, focusing on the use of AR as an instructional medium to enhance the visualization of abstract concepts in Science, and all report positive learning gains Consistent findings are also reported in the research by Siregar and Manurung (2023), which used AR technology to explain photosynthesis, noting that 3D visualization via AR enabled students to understand invisible processes better. This study recorded a 35% increase in conceptual understanding scores from *pretest* to *posttest*. Furthermore, Kurniawan and Wibowo (2022) developed an AR application in Unity 3D for water cycle instruction and found the medium highly effective in enhancing students' memory and engagement (Alalwan et al., 2020). However, a significant gap remains as most existing literature focuses on high-resource educational settings, often overlooking the practical inconsistencies found in regional schools. While theory suggests that AR reduces cognitive load, field data from SDN 16 Koto Baru indicate a controversy: teachers often perceive high-tech media as potentially distracting or technically demanding, leading them to revert to simpler audio-based media. It creates a disconnect between the "ideal" effectiveness of AR reported in literature and the "actual" instructional reality, where audio media is still prioritized for its perceived reliability. There is a lack of empirical evidence explicitly comparing AR against these entrenched audio-based practices to determine if the visual benefits of AR truly outweigh the practical convenience of audio media in resource-constrained environments.

While several studies have examined the positive impact of AR on student learning outcomes, a research gap has not been extensively addressed in prior work. Most existing studies only compare AR media with conventional methods such as lectures or textbooks. Explicit research comparing AR with other digital-based media, such as audio media, is scarce. This gap is significant, as audio media is frequently used as a practical, cost-effective alternative in *blended* or distance learning contexts. Therefore, this study aims to fill this research gap by explicitly comparing the effectiveness of AR media on *Assemblr Edu* with that of audio media in Science instruction for fifth-grade elementary school students. The main contribution of this study is to provide a direct comparison of two types of digital learning media within the context of Science in elementary school. Consequently, this research not only addresses a theoretical gap but also yields significant practical implications for the development of technology-based instructional media at the basic education level. Therefore, it is imperative to empirically examine how such accessible AR tools can bridge the conceptual understanding gap in science among elementary students compared to more traditional, non-visual media, especially in regional areas where digital transformation is still evolving.

METHODOLOGY

This research employed a quasi-experimental approach using a non-equivalent pretest-posttest control-group design. This specific design was chosen because it was not feasible to fully control all extraneous variables that could influence students' Science conceptual understanding. The research subjects were 50 fifth-grade students at SDN 16 Koto Baru, divided into two groups: an experimental class (25 students) that received instruction using Augmented Reality (AR) media via Assemblr Edu, and a control class (25 students) that received instruction using audio media. The research population encompassed all fifth-grade students at SDN 16 Koto Baru during the 2023/2024 academic year. Sampling was conducted using a purposive sampling technique, specifically selecting two classes that exhibited equivalent academic characteristics and initial knowledge levels, and that had equal numbers of students.

The data collection instrument was a 25-item multiple-choice test designed to assess conceptual understanding in Science. The test was administered twice: a pretest before the intervention to determine baseline ability and a posttest after the intervention to measure the final level of conceptual understanding. The instrument underwent both validity and reliability testing. Content validity was established through expert judgment involving three specialists (two lecturers and one practitioner), while item validity was analyzed using the Pearson correlation test on trial data. The reliability was calculated using Cronbach's Alpha, yielding a value of 0.82, indicating high reliability.

The data were analyzed through several stages to ensure a comprehensive evaluation of the intervention. The main data in this study were the students' conceptual understanding scores, obtained from pretest and posttest results. This data is crucial because it serves as the primary indicator of the shift in students' mastery of science concepts after exposure to different learning media. Supporting data included normality and homogeneity test results, which were essential to validate that the data distribution met the assumptions for parametric statistical analysis.

The analysis process was conducted as follows: First, preliminary tests, including normality and homogeneity tests, were conducted to assess assumptions. Second, a paired-samples t-test was performed to determine the difference between the pretest and posttest scores within each group. Third, an independent-samples t-test was conducted to compare posttest scores between the experimental and control classes. Additionally, the N-Gain score was calculated to assess the increase in conceptual understanding, providing a clearer picture of the treatment's effectiveness over time. Finally, Cohen's d was used to determine the effect size of the instructional media used, which is important for quantifying the practical significance and the strength of the impact of AR-based media compared to audio-based media.

RESULT AND DISCUSSION

Pretest and Posttest Data Description

The mean scores and standard deviations for the *pretest* and *posttest* scores of the experimental and control classes are presented in Table 1. The presentation of this data is fundamental to demonstrating the novelty of this research, which lies in the direct empirical comparison between high-interactivity Augmented Reality (AR) and traditional audio-based media, a comparison that remains scarce in elementary science education literature. This data provides a significant contribution to the field of instructional technology by offering concrete evidence on how visual-spatial interventions can overcome the limitations of verbal-auditory methods in teaching abstract scientific concepts. By analyzing these scores, this study reaffirms its importance in identifying more effective digital learning pathways that align with the cognitive development of primary school students, ultimately contributing to the modernization of science pedagogy.

Tabel 1. Results of Student Pretest and Posttest Scores in the Experimental and Control Classes

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
Eksperimental (Media AR)	25	41.6	9.322	67.20	12.168
Control (Media Audio)	25	42.6	12.675	49.00	13.149

Table 1 demonstrates that the *pretest* mean scores for both groups were relatively equivalent (Mexp=41.60, Mcont=42.60), with comparable standard deviations. This indicates that the students' initial abilities were at a nearly identical level. However, the *posttest* results show a notable divergence: the experimental class exhibited an increased mean score of 67.20, while the control class only reached 49.00. This difference suggests that the *Augmented Reality* media based on *Assemblr Edu* made a substantially larger contribution to improving Science conceptual understanding compared to the audio media.

Increase in Science Conceptual Understanding (*N-Gain*)

To ascertain the magnitude of improvement in students' conceptual understanding, the *N-Gain* score was calculated for both groups. This analysis aimed to assess the instructional effectiveness of AR media-based on *Assemblr Edu* versus the use of audio media in the control group, as shown in Table 2.

Tabel 2. N-Gain Scores for Experimental and Control Classes

Group	N	Mean N-Gain	Category
Experimental (AR Assemblr Edu)	25	0.438	Moderate
Control (Media Audio)	25	0.111	Low

Table 2 shows that the increase in Science conceptual understanding in the experimental class was significantly higher than the control class. The experimental group achieved an *N-Gain* of 0.44 (moderate category), whereas the control group obtained an *N-Gain* of 0.11 (low category). This result indicates that the use of AR media provides a more significant impact on students' Science conceptual understanding compared to audio media.

Assumption Testing (Prerequisites for Parametric Analysis)

To ensure that the data met the assumption of a normal distribution, the Shapiro-Wilk test was performed, chosen for its higher sensitivity with small to medium sample sizes. The results are presented in Table 3.

Tabel 3. Normality Test (Shapiro Wilk)

Variable	Test Method	Statistic	p-value	Conclusion (α = 0,05)
Pretest – Exsperimental	Shapiro-Wilk	0.943	0.172	Normal
Postest Exsperimental	Shapiro-Wilk	0.946	0.202	Normal
Pretest Control	Shapiro-Wilk	0.973	0.733	Normal
Posttest Control	Shapiro-Wilk	0.920	0.052	Normal

As shown in Table 3, all variables exhibited a p-value greater than 0.05. Thus, it is concluded that the distribution of *pretest* and *posttest* data for both the experimental and control groups satisfies the normality assumption. Consequently, the use of parametric tests, specifically the *t-test*, for further analysis is deemed appropriate and justifiable.

Additionally, a homogeneity of variances test was conducted using Levene's test (α=0.05) to ensure the equality of variances between groups prior to the intervention. The results are presented in Table 4.

Tabel 4. Homogenity of Variances Test (Levene's Test)

Variable	Test	Statitsic	p-value	Conclusion (α = 0,05)
Pretest Exsperimental vs. Pretest Control	Levene	0.867	0.357	Homogen
Posttest Exsperimental vs. Posttest Control	Levene	0.829	0.353	Homogen

Based on the results in Table 4, the p-values for both the *pretest* and *posttest* comparisons are greater than 0.05. This indicates that the variances between the experimental and control groups are homogeneous. Therefore, the homogeneity assumption is met, validating the subsequent analyses using the *paired-samples t-test* and *independent-samples t-test*. The achievement of this homogeneity is consistent with the rigorous experimental protocols established in international AR research, such as those conducted by Akçayır & Akçayır (2017) and Garzón & Acevedo (2019), who emphasize that ensuring equivalent group variances is essential to isolate the true effect of AR interventions from pre-existing group differences. By meeting this assumption, the current findings align with global standards for quasi-experimental designs in educational technology, ensuring that any subsequent gains in conceptual understanding can be reliably attributed to the implementation of Assemblr Edu-based AR media rather than initial sample disparities (Arici et al., 2019; Cai et al., 2021; Yilmaz et al., 2017).

Hypothesis Testing (t-test Resluts)

To gain a more comprehensive overview of the differences in learning outcomes, inferential statistical analysis was conducted using the t-test. This included the *paired t-test* to examine the difference between *pretest* and *posttest* scores within each group, and the *independent sample t-test* to compare *posttest* results between the experimental and control groups, as summarized in Table 5.

Table 5. T-Test Results

Test Type	Sig. (p)	Std. Dev	Remark
Paired t-test Exsperimental Class	0.000	6.970	Significant difference in pretest-posttest scores in the experimental class
Paired t-test Control Class	0.000	4.682	Significant difference in pretest-posttest scores in the control class
Independent t-test (Post-test)	0.000	12.869	Significant difference between the experimental and control groups

The analysis in Table 5 shows that both the experimental and control groups experienced a significant increase from *pretest* to *posttest*. However, the more substantive difference is demonstrated by the *independent sample t-test* result (p=0.000), which indicates a significant difference between the two groups at the *posttest* stage. It is thus concluded that instruction utilizing *Augmented Reality* media based on *Assemblr Edu* exerts a stronger influence on improving Science conceptual understanding than instruction with audio media.

Effect Size Cohen's D

To determine the magnitude of the effect of *Augmented Reality* media based on *Assemblr Edu* on fifth-grade students' Science conceptual understanding, the effect size analysis using Cohen's *d* was performed. This calculation utilized the descriptive data, including the mean, standard deviation, and sample size for both the experimental and control classes. The complete calculation results are presented in Table 6

Table 6. Mean, Standard Deviation, and Cohen's *d* Calculation for Science Conceptual Understanding

Group	N	Mean	SD	Mean Difference	SD_{pooled}	Cohen's d	Effect Category
Experimental Class (AR Assemblr Edu	25	67.20	12.17	18.20	12.67	1.44	Sangat Besar
Control Class (Audio Media)	25	49.00	13.15				

As indicated in Table 6, a considerable difference in the means exists between the experimental group (M=67.20, SD=12.17) and the control group (M=49.00, SD=13.15). This mean difference of 18.20 yields an effect size (Cohen's *d*) of 1.44, which signifies that the use of *Augmented Reality* media based on *Assemblr Edu* provides a practically significant and very large effect on students' Science conceptual understanding, surpassing the influence of the conventional audio media used in the control class.

To visually clarify the difference in Science conceptual understanding results between the experimental group (using AR media) and the control group (using audio media), the research findings are presented in a bar chart format. This diagram illustrates the mean conceptual understanding scores along with the standard deviations for each group.

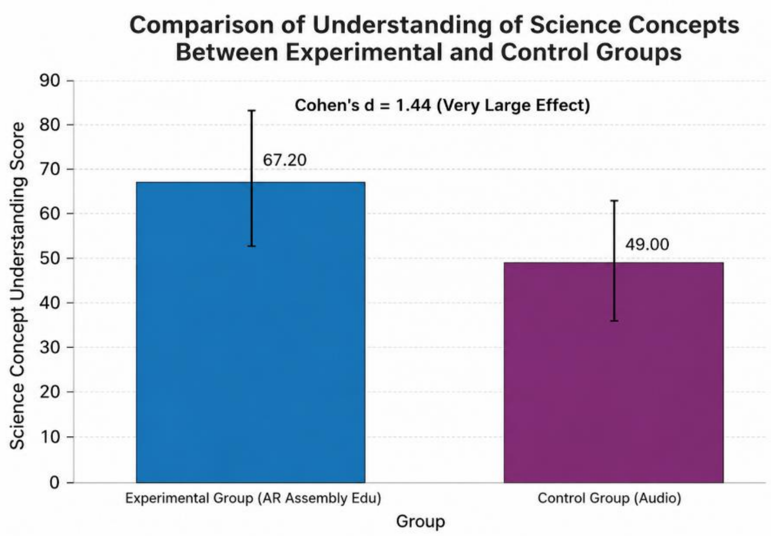

Figure 1. Comparison of Mean Scores for Science Conceptual Understanding

Figure 1 clearly illustrates the disparity in learning outcomes between the experimental and control classes. Students who received instruction using Augmented Reality media demonstrated a significantly higher average learning achievement than those who received instruction only via audio media. This visualization further reinforces the statistical analysis findings, affirming that the observed difference is not only numerically significant but also practically meaningful within the context of Science instruction at the elementary school level.

Discussion

The findings of this study affirm that *Augmented Reality* (AR) media based on *Assemblr Edu* provides a significant impact on improving elementary school students' Science conceptual understanding. This significance is demonstrated by a meaningful difference in the *posttest* results between the experimental and control groups ($p=0.000<0.05$). The increase in conceptual understanding (*N-Gain*) in the experimental group (0.44, moderate category) was substantially higher than that of the control group (0.11, low category). Furthermore, the Cohen's d calculation for *effect size* yielded a value of 1.44 (large category), strongly concluding that AR media has a powerful influence on students' Science conceptual understanding. This suggests that the interactive-visual nature of AR effectively compensates for the cognitive limitations students face when processing abstract science topics through conventional media.

Theoretically, these results align with the constructivist framework. *Augmented Reality* supports Piaget's (1972) view on knowledge construction through active interaction; AR provides visual and manipulative representations that bridge abstract concepts with concrete experiences. In this study, the "how" aspect of AR effectiveness is evident through its ability to transform static textbook illustrations into dynamic 3D models. When students interact with Assemblr Edu, they are not merely passive recipients of information; they perform "virtual manipulation" of scientific objects, such as rotating a 3D model of a plant cell or observing the circulatory system from multiple angles. This active exploration facilitates a deeper cognitive connection than traditional audio-based media, which often lacks the spatial cues needed to understand complex structures. Similarly, AR functions as a *scaffolding* tool that enriches teacher-student interaction and collaboration (Vygotsky, 1978). The technology acts as a "mediator," prompting students to ask more analytical questions and to discuss their visual observations with peers, thereby fostering a social-constructivist classroom environment.

From the perspective of Mayer's (2009) Cognitive Theory of Multimedia Learning, AR provides a dual channel that effectively integrates verbal and visual information, thereby reducing cognitive load and enhancing retention. Specifically, AR minimizes "split-attention effects" by overlaying digital information directly onto the physical learning environment. In the experimental class, students did not have to switch their focus between a separate diagram and a verbal explanation; instead, integrating 3D visuals and concise text within the AR interface enabled more efficient mental model construction. This spatial contiguity is a key factor in why the experimental group achieved significantly higher N-Gain scores (0.44) than the control group (0.11), as it prevents the cognitive system from being overwhelmed by irrelevant processing (Feranie et al., 2022; Garzón & Acevedo, 2019a). These results, therefore, strengthen the validity of classic learning theories while confirming modern empirical findings that position AR as an effective educational technology at the elementary school level.

These findings are consistent with recent literature indicating that Augmented Reality (AR) can enhance students' motivation, engagement, and conceptual understanding in science learning (Bacca et al., 2014; Garzón & Acevedo, 2019b). Contemporary studies further emphasize that AR provides immersive, contextualized learning experiences, enabling students to grasp abstract scientific concepts better (Elfeky & Elbyaly, 2021; Ibáñez & Delgado-Kloos, 2018; Sırakaya & Alsancak Sırakaya, 2020). The effectiveness of AR in this research is also attributed to its "sensory engagement" capabilities. By providing a sense of "presence" or "immersion," students feel a closer connection to the subject matter, which triggers intrinsic motivation—a critical factor in long-term conceptual retention (Radianti et al., 2020). This explains "why" students in the experimental group showed more persistent focus during the learning process. From a theoretical perspective, the results of this study align with constructivist learning theory, which posits that knowledge is actively constructed through meaningful experience.

In this context, AR fosters exploratory and hands-on engagement, allowing students to connect new scientific concepts with their prior knowledge. Additionally, the findings resonate with Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2016), which highlights the dual-channel processing of verbal and visual information. By integrating three-dimensional and interactive elements, AR reduces cognitive load and facilitates deeper conceptual understanding. Furthermore, the outcomes of this study reflect the principles of student engagement theory (Fredricks et al., 2004), as AR promotes behavioral, emotional, and cognitive engagement simultaneously. Behaviorally, students were more active in using the tools; emotionally, the novelty and interactivity of AR reduced learning anxiety; and cognitively, the visualization helped them simplify complex scientific logic. Thus, the study not only corroborates classical theories of learning but also reinforces modern empirical evidence, positioning AR as a highly effective educational technology for elementary science education.

The practical implications of this study are highly relevant to the demands of 21st-century Science education. AR is proven to support the development of critical thinking, problem-solving skills, and digital literacy (Trilling & Fadel, 2009). Teachers can use AR to create more context-rich, collaborative learning experiences for the digital generation. AR implementation thus presents an innovative strategy to reinforce conceptual mastery and prepare students to face global challenges in the digital era. Nevertheless, this study is subject to several limitations. First, the relatively small sample size and restriction to a single school limit the generalizability of the findings. Second, the brief duration of the AR intervention (a few meetings) does not fully represent the long-term impact. Third, the research focused solely on conceptual understanding, while soft skills such as critical thinking, creativity, and scientific attitudes were not explored in depth. Therefore, future research is recommended to involve a broader sample, employ more diverse experimental designs, and include variables relevant to 21st-century competencies. This approach will allow for a more comprehensive understanding of AR's contribution to enhancing the quality of Science education.

CONCLUSION

This study affirms that the use of *Augmented Reality* (AR) media via *Assemblr Edu* makes a significant contribution to improving elementary school students' Science conceptual understanding. Quantitative analysis revealed a significant difference between the experimental and control groups, with the experimental group achieving a moderate *N-Gain* score compared to the control group's low score. Furthermore, the *Cohen's d* calculation yielded a large effect size. These findings indicate that AR is not merely an alternative instructional medium, but rather an effective innovation for integrating interactive visualization and immersive learning experiences to support the construction of students' knowledge.

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